Research Square

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Tumor Control and Hearing Preservation after Gamma Knife Radiosurgery for Vestibular Schwannomas in Neurofibromatosis Type 2- A Retrospective Analysis of 133 Tumors GKRS for Vestibular Schwannoma in NF-2

Gour Surya Sri Krishna
All India Institute of Medical Sciences
Bhavya Pahwa
University College of Medical Sciences and GTB Hospital
Aman Jagdevan
All India Institute of Medical Sciences
Manmohan Singh
All India Institute of Medical Sciences
Shashank Kale
All India Institute of Medical Sciences
Deepak Agrawal (drdeepak@gmail.com)
All India Institute of Medical Sciences

Research Article

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Abstract

Purpose

This study was conducted with the aim to estimate long-term tumor control, hearing preservation rates in patients with NF2 related VS, retreatment success rate and assess the associated predictive factors .

Methods

This was a retrospective analysis of NF2 associated VS who underwent GKRS between 2009 and 2020 and had a minimum follow up of 1 year. Loss of tumor control was defined as greater than 10% increase in volume in more than one follow up imaging or the need for retreatment in the form of repeat GKRS or surgery. Kaplan-Meier method was utilized to evaluate Actuarial tumor control and hearing preservation rates.

Results

85 patients with 133 VSs were included in the study. The mean age was 29.8 years. 57 tumors showed tumor regression, 35 showed stable disease and 23 progressed in size at last follow up. Actuarial tumor control rates after 1, 3, 5, and 9 years were 95%, 79%, 75% and 55% respectively with overall tumor control rate being 85%. Hearing worsened in 39 patients and Facial nerve dysfunction occurred in 4 patients. 5 tumors underwent retreatment with GKRS at a median duration of 27.6 months (19–36 months) following the first GKRS.

Conclusion

This is the largest radiosurgical series of NF2 associated VS reported till date. GKRS provides a high rate of long-term local tumor control with a low risk of neurological deprivation for patients with these tumors. The need for retreatment with GKRS although low, is associated with good tumor control and lesser complications.

Introduction

Neurofibromatosis type 2 (NF2) is an inherited tumor marked by the presence of multiples CNS schwannomas, meningiomas and/or ependymomas with the greatest majority developing bilateral schwannomas of the vestibular nerve, mostly by 30 years of age.[1] Clinical presentation of these tumors include tinnitus, balance dysfunction and progressive hearing loss and most patients commonly lose all functional hearing during early adulthood or middle age. If left untreated, it can extend medially and cause brainstem compression and hydrocephalus. At very young age (< 18 years) individuals presenting

with an apparently isolated meningioma [2] or vestibular schwannoma [3] have a 20% and 10% likelihood respectively of developing NF2.

The clinical management of NF2 patients is a challenging task. Even with improvements in microsurgery, a great majority of individuals with NF2 become completely deaf. There is also risk of other cranial nerve damage, because the tumors tend to be multilobulated and to infiltrate the nerves in NF2 patients.[4] Moreover, the clinical burden of other NF2-associated tumors should be considered before radical surgery is undertaken. The advantage of radiosurgery compared with microsurgery, apart from it being less invasive, is the higher rate of serviceable hearing retained after treatment.[5]

Gamma Knife radiosurgery (GKRS) has proven to be a successful treatment option for small- to medium-sized sporadic vestibular schwannomas.[6] However there is scarce literature regarding the role of GKRS in the treatment of VS in NF2. Hence, the implication of GKRS as a first line treatment modality for VS in NF2 is controversial. Due to more risk of radiation-induced malignant change in NF2 patients as compared to the sporadic cases post GKRS and variability in the reported outcomes, patients should be counseled and prepared accordingly.[7] The tumor may also be more difficult to excise after radiotherapy, and that reported facial nerve outcomes after surgery following stereotactic radiation therapy are frequently poor. he aim of the present study was to study the extent of tumor control and hearing preservation among patients with vestibular schwannomas associated with Neurofibromatosis type 2 undergoing Gamma Knife radiosurgery(GKRS)

Methodology

Patient Population

This was a retrospective analysis wherein prospectively maintained database of all patients with VS treated with GKRS at the Gamma Knife Center, AIIMS, New Delhi, India between January 2009 and January 2020 was reviewed. We included the patients with vestibular schwannoma, either unilateral or bilateral receiving GKRS and fulfilling Manchester criteria [8] for diagnosis for NF2. Patients with NF2 who underwent GKRS for non-VS tumors alone were excluded. Patients in whom bilateral VS were targeted were included in the analysis as separate cases. Ethical clearance was obtained from the Institute Ethics Committee. Patients and relatives were extensively counseled regarding goals of GKRS, tumor control rates, expected hearing preservation, and anticipated complication rates. Patients with bilateral VS and intact hearing, or in patients on the side of the only functioning ear until the patient could train themselves to lip read, did not undergo GKRS. Patient's preference for the type of intervention was also taken into account. GKRS was performed for small to medium-large tumors with radiological progression (10 % or more on follow up imaging), presenting with or without progressive hearing loss. Surgery was advised in patients having tumors with a large volume at initial presentation. There is no well-defined volumetric cut-off to decide whether to treat larger tumors with radiosurgery or microsurgery. Generally radiosurgery is indicated for the patients with tumors with a size less than 3 cm, unless symptoms of mass effect are present. Microsurgery or debulking followed by GKRS is advised in the

management of tumors larger than 3cm. The decision to treat with GKRS was taken by the radiosurgical team, composed of a neurosurgeon and a radiation oncologist.

GKRS Procedure

Until February 2011, a total of 14 tumors were treated with the Leksell model B® unit (Elekta AB, Stockholm, Sweden). Thereafter, tumors were treated with the Leksell Gamma Knife Perfexion® (Elekta AB, Stockholm, Sweden). A Leksell Model G® head frame (Elekta AB, Stockholm, Sweden) was placed under local anesthesia as per the location of tumor on radiological evidence. Planning was done using Leksell GammaPlan software® (Elekta AB, Stockholm, Sweden). Localizing magnetic resonance imaging (MRI) was performed using contiguous 1 mm slice thickness axial T1-weighted contrast-enhanced images (TR 19.8 ms, TE 3.3 ms, FOV 256mm, flip angle 12°, pixel spacing 0.5x0.5mm, square matrix of 256x256). Spatial distortion was minimized by shimming. Stereotactic images were acceptable only after the gamma plan indicated a mean error of deviation of less than 1 mm.

The marginal dose was prescribed between 10-15 Gy, delivered at 50% isodose line, with at least 90% tumor coverage and the safety tolerance limits decided based on treating neurosurgeon's preference and presence of adjoining structures. Dosimetric analysis included prescription dose, marginal and maximum doses to the tumors in all patients and marginal and maximum dose to the cochlea in patients with serviceable hearing prior to GKRS.

Follow-Up Evaluations

Only patients with a minimum follow up of 1 year were included in the study. Both clinical and radiological follow-up evaluation was done. Follow-up intervals were shortened if there was any hearing deterioration or radiologic evidence of progression.

Volume calculation

Tumor volume was assessed by one of the investigators using post gadolinium MRI images. Tumor volume was calculated using tumor marking in GK software or by measuring the radius of the lesion on MRI scans in three planes (r1–r3) and using the following formula:

$V=(4\Pi/3)\ r1\times r2\times r3$

The effect of GKRS was evaluated based on follow-up MRI images. In our study we have used a cutoff of more than 10% increase in volume for radiological progression. Tumor regression was defined as more than 10% decrease in tumor volume whereas stable tumor was defined as being within these limits. Loss of tumor control was defined as an increase in tumor volume in follow up imaging by 10% or more, or the requirement of an additional treatment modality (GKRS or microsurgery) due to confirmed growth on consecutive MRI studies or worsening of symptoms (i.e., brainstem compression). Pseudoprogression was defined as tumor expansions due to transient radiation-induced swelling and the patients with pseudoprogression were not considered as loss of tumor control. Finally, the decision about additional

treatment was made by a medical board consisting of a neurosurgeon, a radiation oncologist, and a radiologist.

Definition of phenotype

Wishart phenotype was considered if patients were less than 20 years of age with bilateral VS and associated other cranial and spinal tumors. Patients not fulfilling these criteria were noted to belong to the Feiling Gardner phenotype.

Assessment of complications

Hearing preservation rates were estimated using audiometry before and after GKRS. Serviceable hearing was defined as Gardner-Robertson Hearing Scale, Grade I and II. Other neuronal complications such as facial neuropathy, graded according to the House-Brackmann (H & B) grading system and trigeminal neuropathy (i.e. numbness, paresthesia, or neuralgia) were recorded before and after GKRS until the last follow up. Additionally, complications like hydrocephalus requiring CSF diversion were recorded. In case of missing data or loss of patients to follow-up, telephonic interview was performed in an attempt to collect the missing data.

Statistical Analyses

Tumor control rates and hearing preservation rates were estimated using the Kaplan-Meier method. Univariate and Multivariate analyses were performed to assess the impact of factors of interest (patient-age at the time of radiosurgery, phenotype, tumor volume and treatment related-mean dose tumor, maximum dose tumor) on progression-free survival (PFS) and hearing preservation. The analysis was performed using SPSS version 20 (IBM Corp.).

Results

Patient characteristics (Table 1)

A total of 1128 VS underwent GKRS from January 2009-January 2020, of which there were 98 NF2 patients (155 VS). Finally, 85 patients (133 VS) with a minimum of one year of follow up were included in the study. The mean age was 29.88 years, with the youngest patient being 12 years old whereas the oldest patient was 65 years of age. Patients belonged predominantly to younger age groups i.e., 10-30 years (n=50) with 8 tumors noted in the 50-65 years age group. Tumor was noted to be more common in men with the M: F ratio being 11:6

13 patients had unilateral tumors whereas 72 patients had bilateral tumors. Among patients with bilateral tumors only one side tumor was irradiated in 24 patients and the rest were irradiated on both sides, of which 37 patients were irradiated in the same sitting whereas in 11 patients the contralateral VS was treated during follow up either due to worsening of hearing or progression in tumor size **(Figure 1)**. The tumors had no side predilection, with 67 tumors located on the left side.

67 patients belonged to the Feiling Gardner phenotype while the rest of them belonged to Wishart phenotype (n=18). 47 patients had associated other cranial or spinal tumors, 34 patients had associated cranial tumors like multiple meningiomas, other cranial nerve schwannoma, orbital tumors, ependymoma, 22 patients had associated spinal tumors like ependymoma, schwannoma, neurofibroma and 10 patients had both associated cranial and spinal tumors. 10 patients had a positive family history for NF2.

Most of the tumors received primary GKRS (n=101, 75.9%) while the rest received as an adjunct following surgery (n=32, 24.1%), secondary GKRS.

Symptom distribution (Table 1)

Hearing loss was the most common symptom, noted in almost all tumors (n=129, 97%). Facial palsy and tinnitus was the second and third most common symptom noted in 25 (18.8%) and 20 tumors respectively (15%). 13 tumors (9.7%) had a facial palsy of H&B grade >2

Dosimetric analysis

The mean tumor size was 4.22 cm^3 ranging from 0.16cm^3 to 24.36cm^3. The median marginal dose was 12 Gy (11.5Gy- 15Gy). The mean maximum dose was 24.36Gy (17.3-30.6) and the mean dose was 16.2Gy (12.3-21.1 Gy)

Follow up:

71 patients with 115 tumors had minimal radiological follow up of 12 months with the median and mean duration being 26 months (14-111 months). 118 tumors were available for clinical follow-up with a median duration of 24 months (12-111 months).

Tumor control

57 tumors (49.6%) showed tumor regression, 35 tumors (30.4%) showed stable disease and 23 tumors progressed in size (15%) at last follow-up. The actuarial tumor control rate was 100% at 1 year, 84% at 2 years, 79% at 3 years, 75% at 5 years, 75% at 6 years and 55% at 9 years. (**Figure 2a)**

A Cox regression analysis was done to identify factors which could predict loss of tumor control. None of the factors reached statistical significance **(Table 2).**

`Hearing preservation

15 tumors had no audiological follow up (11.2%). At last follow-up, 25 tumors had retained serviceable hearing (61.7% of previous serviceable hearing). No patients had subjective improvement in hearing following gamma knife. A total of 39 tumors had worsening of hearing in the follow up period, with 79 tumors retaining the same hearing, giving a total hearing preservation rate of 66.9%.

The actuarial hearing preservation rate was 100% at 1 year, 70% at 2 years, 66% at 3 years, 55% at 5 years, 50% at 6 years and 25 % at 9 years. **(Figure 2b)**

Pre GKRS, there were 4 patients with grade 0, 10 with grade 1, 34 with bgrade 2, 46 with grade 3 and 39 with grade 5. Post GKRS, 2 patients each had grade 1 and grade 2 of hearing, 21 patients had grade 3, 34 patients had grade 4 and 61 patients had grade 5.

A univariate analysis was done to identify factors which could predict serviceable hearing preservation post GKRS. None of the factors attained statistical significance **(Table 3).**

Complications

There was no treatment related mortality noted. Facial palsy worsened in 4 patients out of 118. Of these two had SGKRS. One patient developed left facial pain which was transient, lasted for 6 months, managed with medications.

3 patients required shunt during the follow up period. 2 patients underwent surgery following GKRS in view of tumor progression and brainstem compression of which 1 patient expired due to tumor related complications.

Retreatment

Retreatment was needed for 6 patients with 7 tumors, of which 5 tumors required repeat GKRS and 2 tumors required surgery.

Repeat Surgery

Two patients underwent surgery following GKRS. Both patients had bilateral tumors. There was no gender predilection, no positive family history was noted. 1 patient each belonged to both phenotypes. Mean tumor volume ws 13.35 m^3 that received a mena marginal dose of 14Gy. The median age was 23.5 years (20-27 years). Both had received primary GKRS. Median time to loss of control was 43.5 months (10-77 months). One patient expired in the postoperative period outside. The other patient had a very small residual tumor at 23 months follow up. There was deterioration in hearing from grade 4 to 5 and facial palsy deteriorated from grade 2 to 4.

*Repeat GKRS (Illustrative case in **Figure 3)***

4 patients with 5 tumors required repeat GKRS in view of tumor progression. 1 patient had unilateral tumor whereas the rest had bilateral tumors **(Table 4).**

Tumor control at follow up after repeat GKRS *(Illustrative case in **Figure 4)***

Median time to loss of control was 27.6 months (19-36 months). Follow up was available for 3 tumors as two tumors had a follow up of less than 12 months following repeat GK. Median follow up was 19

months (14-22 months). All tumors showed tumor regression at last follow up**.** One patient developed worsening of hearing from grade 2 to grade 4 and new onset facial palsy. No new onset trigeminal dysfunction was noted.

Discussion

This is the largest series of NF2 associated VS reported in the literature till date. Although Spatola et al. [9] reported on more patients (n=103), the study included only 129 VS. There was no gender predilection in our study which was comparable to the studies by Roche et al. [10] and Phi et al. [11] Most studies on NF2 show preponderance of females. [12-14] The median age was 29.8 years (12-65 years) which was comparable with previous studies. [10, 13. 15, 16] 21.2% of patients belonged to severe Wishart phenotype which was lesser when compared to studies by Sun et al. (44%) [16] and Shinya et al (37%). [14] This could be attributed to lack of strict definition of phenotype or we suspect the presence of different phenotypic presentations in the Indian population. About 55.3% VS had associated tumors at presentation in this series which is lesser when compared to 66% reported by Kruyt et al. [5] The symptom distribution was also comparable with previous studies. The mean tumor volume and median marginal dose of our study was comparable to the recently published studies.

Tumor control

Various criteria have been used for definition of tumor control in previous studies like the need for surgery or repeat GKRS or change in any dimension by 2mm or change in tumor volume by 10% or 20%. We had taken a criteria of increase in volume by 10% on more than one consecutive follow up imaging or the need for intervention in the form of repeat GKRS or surgery, as previously reported by Sun et al. and Spatola et al. [9,16]

At last follow-up, 57 tumors showed tumor regression, 35 tumors (30.4%) showed stable disease and 23 tumors progressed in size giving an overall tumor control rate of 85%. Of the 23 tumors which showed radiological progression, only 7 tumors required repeat GKRS or surgery while rest were managed conservatively with serial imaging in view of lack of worsening of symptoms or brainstem compression. The significant number of patients managed conservatively could be attributed to using stricter criteria of 10% increase in volume.

The actuarial tumor control rate was 95% at 1 year, 84% at 2 years, 79% at 3years, 75% at 5 years and 55% at 9 years. It is better than control rates reported by Sharma et al. [13] which was a study published earlier from the same center, and similar to control rate reported by Roche et al. [10] It is not prudent to compare tumor control rates across studies as different criteria for tumor control were used and the follow up duration was different. It is to be noted here that most of the loss of tumor control occurred between 1-2 years of follow up which lead to lower overall control rate at end of followup.

Various indicators have been found to predict loss of tumor control like presence of Wishart phenotype or size >6cm^3 as reported by Kruyt et al. [5] However in our study none of the variables attained statistical

significance. This could be attributed to stricter enrolment criteria in this study and smaller tumors and lesser patients with Wishart phenotype.

Hearing preservation

97% of patients (n=129) had impairment of hearing prior to GKRS. Interestingly 4 tumors had normal hearing at presentation. A total of 36% patients had serviceable hearing pre-GKRS. Serviceable hearing preservation rate was 61.7% till the last follow up. This rate was comparable to studies previously published. [11,13] None of the factors were predictors of preservation of serviceable hearing post GKRS in univariate analysis. Although variables like family history, pre- GKRS serviceable hearing, and indication of GK were found to be significant, the association was found to be spurious. Few studies have reported factors like larger tumor size, higher maximum tumor dose, pre- GKRS serviceable hearing to be significant in univariate analysis however they were not significant in multivariate analysis. Various mechanisms of hearing loss have been proposed like mechanical compression by tumor, increased intralabyrinthine protein, cochlear duct obstruction, intralabyrinthine hemorrhage, endolymphatic hydrops, intralabyrinthine schwannomas but none of it is clear. [16] We believe that the hearing outcome is a multifaceted issue and has to be interpreted with caution, since it could be a complication of GKRS itself or some mechanisms which have no relation to GKRS. Due to unavailability of follow up data for all patients we cannot comment fully on that, however, we have provided Kaplan Meier curve for actuarial hearing preservation which was predicted to decrease with time **(Figure 2b)**

Complications

Facial palsy worsened in 4 out of 118 tumors who were available for clinical follow up. All of them had bilateral tumors and half of them received primary GKRS. The facial palsy was persistent with no resolution till last follow up in all the cases. About 1.65% could be truly attributed to GKRS as two patients had undergone surgery previously. Various studies have reported facial nerve deterioration post GKRS ranging from 2.3-19% with permanent deficit rate ranging from 1.6-19%. [5,10,11,13-15] The facial nerve rate reported in this study is comparable to most of the previously reported studies. The various causes include high marginal dose, previous surgery, tumor progression, facial nerve schwannoma.

One patient developed trigeminal neuralgia at 29 months of follow up which was transient and managed conservatively, the same patient developed facial palsy post GKRS. This rate is lower when compared to previously published studies which could be attributed to better planning and strict adherence to lower marginal dose.

Two patients required CSF diversion in the follow up period. Both patients had bilateral tumors of which one had received GK for one tumor while the other received for both. Shunt was done at 1 and 2 years following GKRS respectively. One patient died during follow-up at 4 years who required surgery in view of tumor progression and developed tumor related complications. There were no cases of radiation- induced malignancy in this series.

Retreatment

Tumor control at follow up (after repeat GKRS)

There is paucity of literature reported on retreatment following GKRS and that too it has been reported on sporadic VS only. **This study describes the retreatment rates for NF2 associated VS for the first time.**

Role of newer therapies

Recently Bevacizumab, an anti-VEGF monoclonal antibody's role has been described for hearing preservation and tumor control in NF2 associated vestibular schwannomas. Plotkin et al. [18] had noted a median volumetric reduction of 26% in 10 patients treated with bevacizumab and improvement in hearing in 4 out of 7 eligible patients and stable response in 2. Recent studies have shown better results with reduction in tumor size in 39% patients and stabilization in 51% patients.[19] However long term toxic effects need to be taken into account as a benign condition is being treated, also the possibility of rebound response on stopping monoclonal treatment. complications have been reported in studies with fatigue being the most common (43%) followed by epistaxis (29%), and proteinuria (29%). [20]

Malignant transformation potential

Following GKRS, the malignant transformation of VS in NF2 patients is minimal because for a benign NF2 associated VS to get transformed into malignant tumor, the cahan's criteria is not really fulfilled owing to the non histological identification of the tumor before the treatment which makes it difficult to recognize the tumor as benign or malignant. Seferis et al. [21] reported malignant transformation in 11 patients post GKRS for VS at a median follow-up of 60 months. However, Cahan's criteria was just fulfilled in one case. The overall risk of malignant transformation in VS patients (sporadic+NF2) over a period of 20 years was 25.1 per 100,000. They also suggested the risk post GKRS in such patients increased by a factor of 15. Risk was estimated to be 4177 per 100,000 on the basis of a patient size of 1348 with NF2. [22] Rowe et al. evaluated an estimated value of risk to be 1-2%.[7] However, similar to our study, Kruyt et al. [5] did not find any risk of malignant transformation in their study.

Limitations

Few studies have mentioned about the worsening of the hearing rates over a long follow up duration. The biggest limitation we feel is the short duration of follow up in our study, which could have presented a better or worse tumor control and hearing preservation.

Conclusion

This study is the largest radiosurgical series of NF2 associated VS in the world literature. Our study shows that GKRS provides a high rate of long-term local tumor control with a low risk of neurological injury for patients with these tumors. GKRS can be used safely and effectively with limited side effects as a primary management tool in NF2 patients with small and moderate sized vestibular schwannomas.

GKRS has the added advantage of treating associated tumors in the same sitting. For the first time, patients who underwent retreatment, either with repeat GKRS or surgery were analyzed.

Declarations

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The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Tables

Table 1: Demographic variables, baseline characteristics and clinical presentations of patients.

Characteristic	Value
Age	29.8 years (12-65)
Gender	
• Male	55 64.7%)
• Female	30 (35.3%)
GKRS	
• Primary	101 (75.9%)
• Secondary (following microsurgical resection)	32 (24.1%)
Phenotype	
• Wishart	18 (21.2%)
• Feiling Gardner	67 (78.8%)
Tumors other than VS at time of GKRS	
• None	38
• Cranial tumor(s)	34
• Spinal tumor(s)	22
• Cranial and spinal tumor(s)	10
Frequency	
• Unilateral	13
• Bilateral	72
Side	
• Right	66
• Left	67
Family history	10 (11.8%)
Symptoms	
• Hearing loss	129 (97%)
• tinnitus	20 (15%)
• facial palsy	25 (18.8%)
• ataxia	11 (8.3%)
• facial numbness	6 (4.5%)
• impaired gag	5 (3.8%)

• headache	5	(3.8%)
• vision loss	4	(3%)
• asymptomatic	2	(1.5%)

Table 2. Table depicting Cox regression analysis of factors which could predict loss of tumor control

Variable	Odds ratio	Confidence interval	p value
Age	1.02	0.96-1.07	0.451
Gender	1.48	0.39-5.59	0.562
Laterality	1.22	0.06-23.42	0.893
Phenotype	1.00	0.16-6.23	0.995
Type of GK	0.67	0.05-8.03	0.754
Family history	2.03	0.39-10.5	0.395
Tumor size	1.06	0.91-1.24	0.404
Associated tumors	1.18	0.33-4.27	0.791
Max dose >26 cc	0.49	0.04-5.59	0.568
Pre- GK hearing	2.21	0.52- 9.42	0.28

Table 3. Logistic regression analysis of factors which could predict serviceable hearing post GKRS

Variable	p value
Laterality	0.159
Gender	0.375
Positive family history	0.855
Associated tumors	0.689
Wishart phenotype	0.75
Pre GK serviceable hearing	0.125
Age	0.441
Tumor size	0.651
Maximum dose	0.504
Median Marginal Dose	0.614
Mean dose	0.764

Table 4. Baseline characteristics of patients who underwent repeat GKRS

Characteristic	Value (n, %)
Age in years, mean (range)	36.5 (26-65)
Male gender	2 (50%)
Feiling Gardner phenotype	4 (100%)
Family history	2 (50%)
Primary GKRS	5 (100%)
Tumor volume in cm^3, mean (range)	2.61 (0.53-7.32)
Maximum dose in Gy, mean(range)	24.45 (24.2-24.6)
Margin dose in Gy, median(range)	12 (10.5-15)

Figures

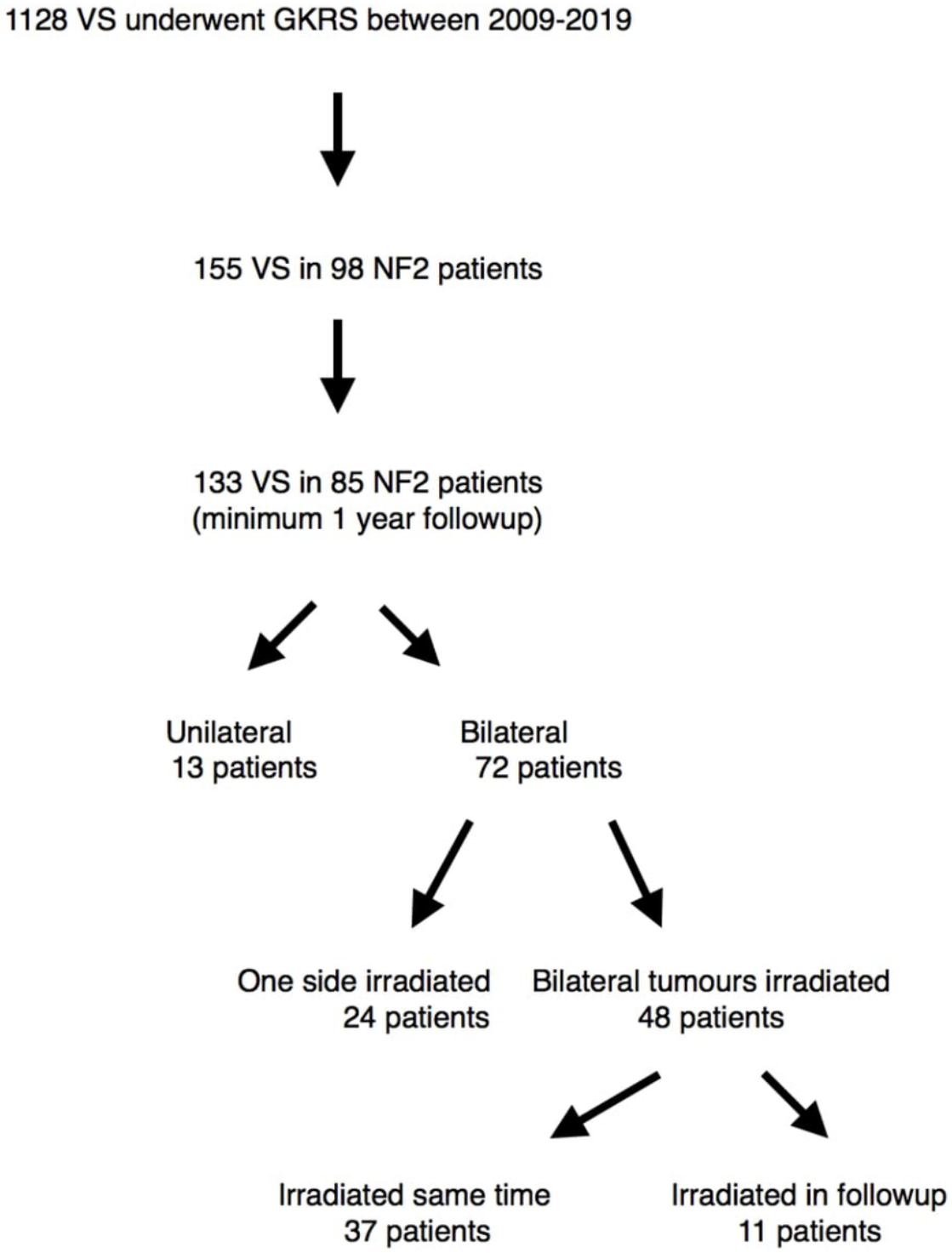
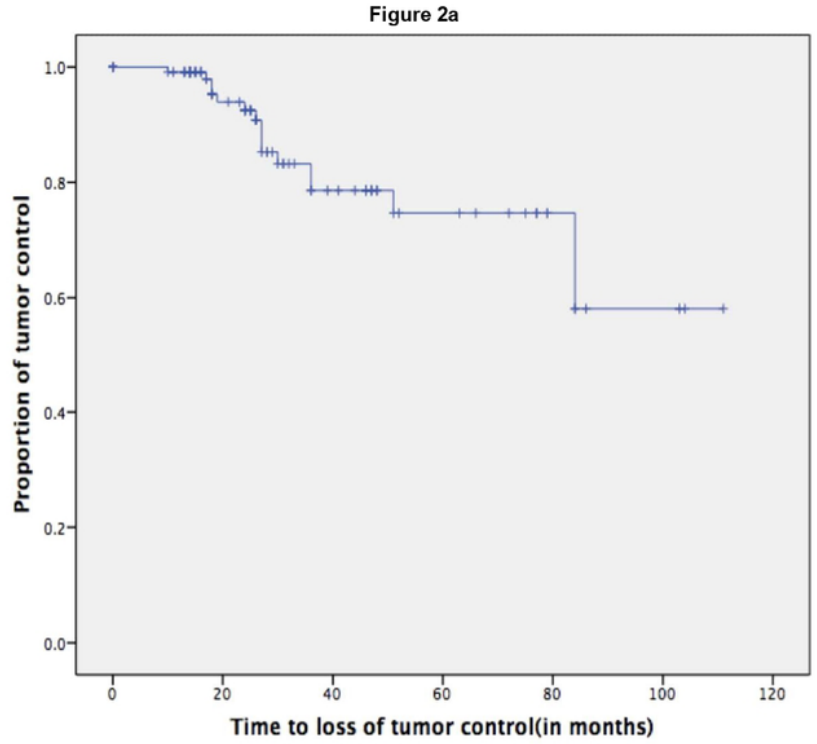


Figure 1

Flow chart depicting the distribution of NF2 patients



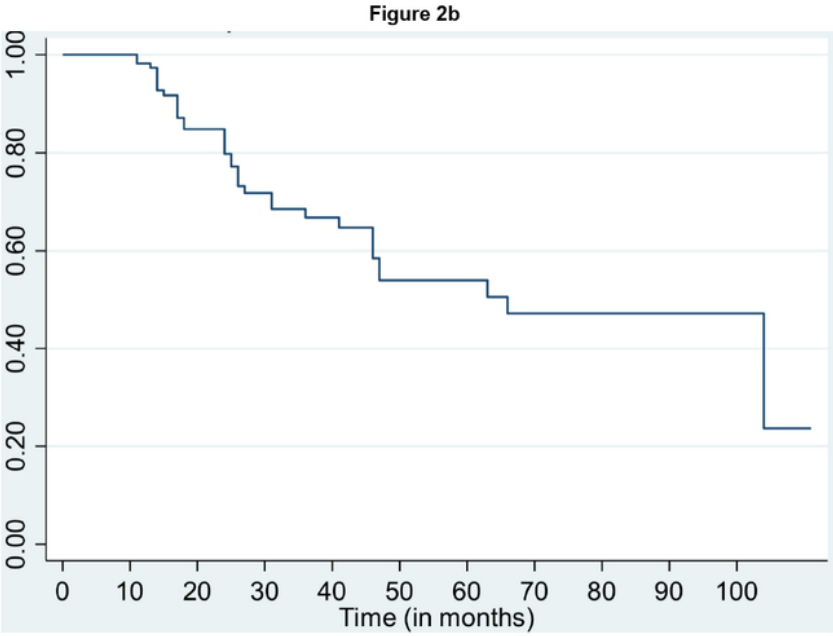


Figure 2

a Kaplan-Meier plot illustrating overall tumor control rates for 133 Neurofibromatosis 2- related Vestibular Schwannoma in 85 patients **b** Kaplan-Meier plot illustrating hearing preservation rates post Gamma Knife Radiosurgery in patients with Neurofibromatosis 2- related Vestibular Schwannoma

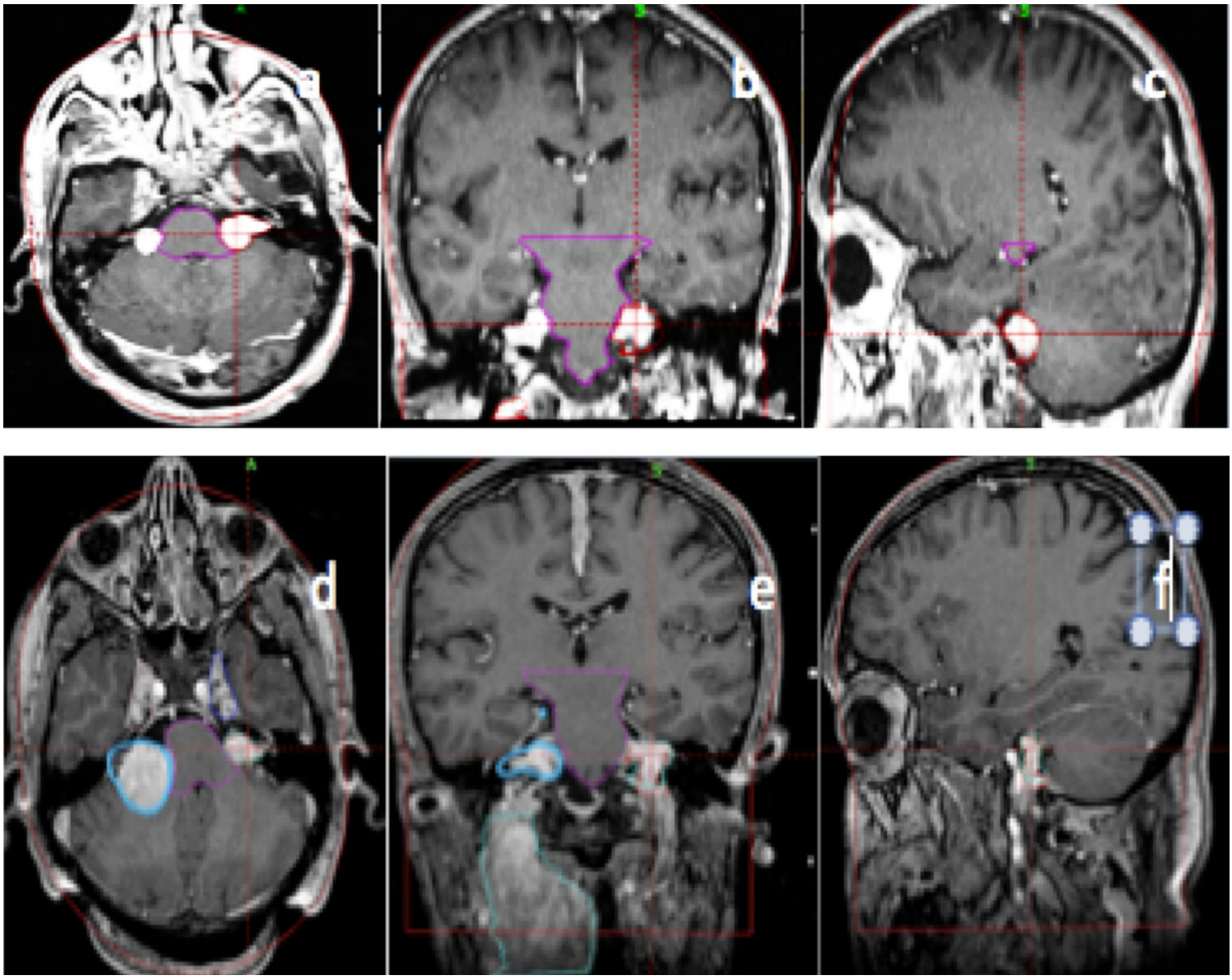


Figure 3

Imaging at baseline (a-axial, b-coronal, c-sagittal) of a patient with bilateral VS who underwent primary GKRS of left VS. Follow up imaging at 104 months (d-axial, e-coronal, f-sagittal) demonstrated tumor regression. Also to be noted here is the progression of right VS requiring GKRS

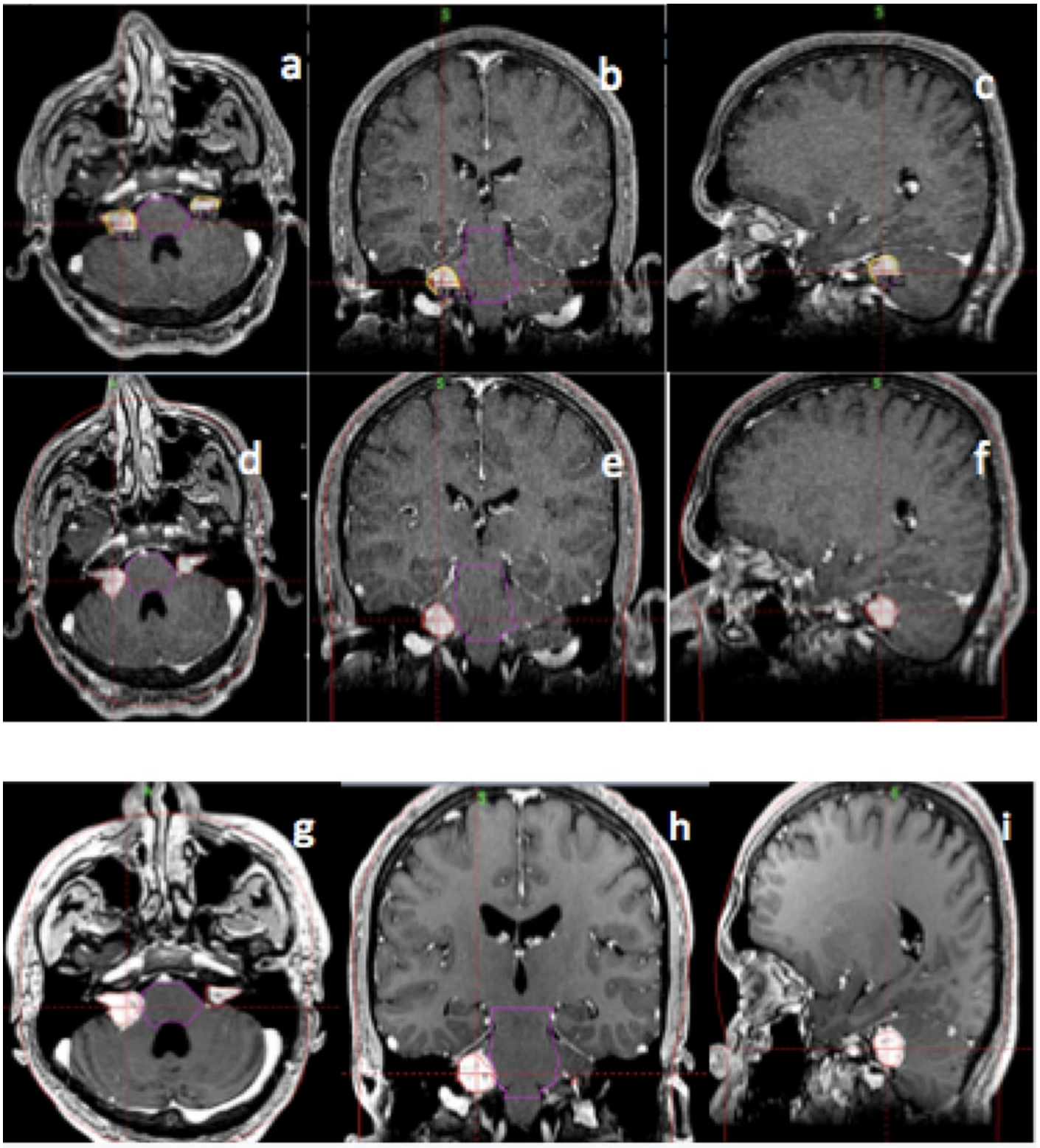


Figure 4

Pre- GKRS images (a-axial, b-coronal, c-sagittal) of a patient who underwent primary GKRS of a right VS. Imaging at 19 months follow up (d-axial, e-coronal, f-sagittal) showed tumor progression with development of grade 2 facial palsy requiring repeat GKRS. Imaging at 22 months following repeat GKRS (g-axial, h-coronal, i-sagittal) showed stable tumor